Chapter 1
Introduction

This document presents the results of a cleaner technologies substitutes assessment (CTSA) of seven technologies for performing the “making holes conductive” (MHC) function during the manufacture of printed wiring boards (PWBs). MHC technologies are used by PWB manufacturers to deposit a seed layer or coating of conductive material into the drilled through-holes of rigid, multi-layer PWBs prior to electroplating. The technologies evaluated here are electroless copper, carbon, conductive polymer, graphite, non-formaldehyde electroless copper, organic-palladium, and tin-palladium. Chemical and process information is also presented for a conductive ink technology, but this technology is not evaluated fully.[1]

For the purposes of this evaluation, the non-conveyorized electroless copper process is considered the baseline process against which alternative technologies and equipment configurations (e.g., non-conveyorized or conveyorized) are compared. This CTSA is the culmination of over two years of research by the U.S. Environmental Protection Agency (EPA) Design for the Environment (DfE) PWB Project and the University of Tennessee (UT) Center for Clean Products and Clean Technologies on the comparative risk, performance, cost, and natural resource requirements of the alternatives as compared to the baseline.

The DfE PWB Project is a voluntary, cooperative partnership among EPA, industry, public-interest groups, and other stakeholders to promote implementation of environmentally beneficial and economically feasible manufacturing technologies by PWB manufacturers. Project partners participated in the planning and execution of this CTSA by helping define the scope and direction of the CTSA, developing project workplans, donating time, materials, and their manufacturing facilities for project research, and reviewing technical information contained in this CTSA. Much of the process-specific information presented here was provided by chemical suppliers to the PWB industry, PWB manufacturers who responded to project information requests, and PWB manufacturers who volunteered their facilities for a performance demonstration of the baseline and alternative technologies.

Section 1.1 presents project background information, including summary descriptions of the EPA DfE Program and the DfE PWB Project. Section 1.2 is an overview of the PWB industry, including the types of PWBs produced, the market for PWBs, and the overall PWB manufacturing process. Section 1.3 summarizes the CTSA methodology, including a discussion of how technologies were selected for evaluation in the CTSA, the boundaries of the evaluation, issues evaluated, data sources, and project limitations. Section 1.4 describes the organization of the remainder of the CTSA document.

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[1] Only limited analyses were performed on the conductive ink technology for two reasons: 1) the process is not applicable to multi-layer boards, which were the focus of the CTSA; and 2) sufficient data were not available to characterize the risk, cost, and energy and natural resources consumption of all of the relevant process steps (e.g., preparation of the screen for printing, the screen printing process itself, and screen reclamation).

1.1 PROJECT BACKGROUND

The PWB is the underlying link between semiconductors, computer chips, and other electronic components. Therefore, PWBs are an irreplaceable part of many "high-tech" products in the electronics, defense, communications, and automotive industries. PWB manufacturing, however, typically generates a significant amount of hazardous waste, requires a substantial amount of water and energy, and uses chemicals that may pose potential environmental and health risks.

To address these issues, the PWB industry has been actively seeking to identify and evaluate cleaner technologies and pollution prevention opportunities. However, many PWB manufacturers are small businesses that cannot afford to independently develop the data needed to evaluate new technologies and redesign their processes. The DfE PWB Project was initiated to develop that data, by forming partnerships between the EPA DfE Program, the PWB industry, and other interested parties to facilitate the evaluation and implementation of alternative technologies that reduce health and environmental risks and production costs. The EPA DfE Program and the DfE PWB Project are discussed in more detail below.

1.1.1 EPA DfE Program

EPA's Office of Pollution Prevention and Toxics created the DfE Program in 1991. The Program uses EPA's expertise and leadership to facilitate information exchange and research on risk reduction and pollution prevention opportunities. DfE works on a voluntary basis with small- and mostly medium-sized businesses to evaluate the risks, performance, costs, and resource requirements of alternative chemicals, processes, and technologies. Additional goals of the program include:

- Changing general business practices to incorporate environmental concerns.
- Helping individual businesses undertake environmental design efforts through the application of specific tools and methods.

The DfE Program catalyzes voluntary environmental improvement through stakeholder partnerships. DfE partners include industry, trade associations, research institutions, environmental and public-interest groups, academia, and other government agencies. By involving representatives from each of these stakeholder groups, DfE projects gain the necessary expertise to perform the project's technical work and improve the quality, credibility, and utility of the project's results.

1.1.2 DfE Printed Wiring Board Project

The DfE PWB Project is a voluntary, cooperative partnership among EPA, industry, public-interest groups, and other stakeholders to promote implementation of environmentally beneficial and economically feasible manufacturing technologies by PWB manufacturers. In part, the project is an outgrowth of industry efforts to identify key cleaner technology needs in electronic systems manufacturing. The results of these industry studies are presented in two reports prepared by Microelectronics and Computer Technology Corporation (MCC), an industry research consortium: *Environmental Consciousness: A Strategic Competitiveness Issue for the*

Electronics Industry (MCC, 1993) and *Electronics Industry Environmental Roadmap* (MCC, 1994).

The first study identified wet chemistry processes, such as those used in PWB fabrication, as water- and energy-intensive processes that generate significant amounts of hazardous waste. The study concluded that effective collaboration among government, industry, academia, and the public is imperative to proactively address the needs of environmental technologies, policies, and practices (MCC, 1993). As follow-up, the industry embarked on a collaborative effort to develop an environmental roadmap for the electronics industry. The roadmap project involved more than 100 organizations, including EPA, the Department of Energy, the Advanced Research Projects Agency, and several trade associations. The PWB industry national trade association, the Institute for Interconnecting and Packaging Electronic Circuits (IPC), was instrumental in developing the information on PWBs through its Environmental, Health, and Safety Committee.

The highest priority need identified for PWB manufacturers was for more efficient use, regeneration, and recycling of hazardous wet chemistries. One proposed approach to meet this need was to eliminate formaldehyde from materials and chemical formulations by researching alternative chemical formulations. Another priority need for the industry was to reduce water consumption and discharge, which can also be accomplished with alternative wet chemistries that have reduced numbers of rinse steps. Electroless copper technologies for MHC use formaldehyde as a reducing agent and consume large amounts of water.

The potential for improvement in these areas led EPA's DfE Program to forge working partnerships with IPC, individual PWB manufacturers and suppliers, research institutions such as MCC and UT's Center for Clean Products and Clean Technologies, and public-interest organizations, including the Silicon Valley Toxics Coalition and Communities for a Better Environment. These partnerships resulted in the DfE PWB Project.

Since its inception in 1994, the primary focus of the Project has been the evaluation of environmentally preferable MHC technologies. This CTSA is the culmination of this effort. The project has also:

- Identified, evaluated, and disseminated information on viable pollution prevention opportunities for the PWB industry through a review of pollution prevention and control practices in the industry (EPA, 1995a).
- Prepared several case studies of pollution prevention opportunities (EPA, 1995b; EPA, 1995c; EPA, 1996a; EPA, 1996b; EPA, 1996c).
- Prepared a summary of federal environmental regulations affecting the electronics industry (EPA, 1995d).
- Developed a summary document that profiles the PWB industry and defines and describes the typical manufacturing steps in the manufacture of rigid, multi-layer PWBs (EPA, 1995e).
- Prepared an implementation guide for PWB manufacturers interested in switching from electroless copper to an alternative MHC technology (EPA, 1997).

Future activities will include an evaluation of alternative surface finishes that can substitute for the hot-air solder leveling process.

1.2 OVERVIEW OF PWB INDUSTRY

1.2.1 Types of Printed Wiring Boards

PWBs may be categorized in several ways, including by layer counts or by substrate. Layer counts are the number of circuit layers present on a single PWB, giving an indication of the overall complexity of the PWB. The most common categories of layer counts are multi-layer, double-sided, and single-sided PWBs. Multi-layer PWBs contain more than two layers of circuitry, with at least one layer imbedded in the substrate beneath the surface of the board. Multi-layer boards may consist of 20 or more interconnected layers, but four, six, and eight layer boards are more common. Double-sided boards have circuitry on both sides of a board, resulting in two interconnected layers, while single-sided PWBs have only one layer of circuitry. Double-sided and single-sided PWBs are generally easier to produce than multi-layer boards (EPA, 1995e).

PWB substrates, or base material types, fall into three basic categories: rigid PWBs, flexible circuits, and rigid-flex combinations. Rigid multi-layer PWBs dominate the domestic production value of all PWBs (see Section 1.2.2, below) and are the focus of this CTSA.

Rigid PWBs typically are constructed of glass-reinforced epoxy-resin systems that produce a board less than 0.1" thick. The most common rigid PWB thickness is 0.062", but there is a trend toward thinner PWBs. Flexible circuits (also called flex circuits) are manufactured on polyamide and polyester substrates that remain flexible at finished thicknesses. Ribbon cables are common flexible circuits. Rigid-flex PWBs are essentially combinations or assemblies of rigid and flexible PWBs. They may consist of one or more rigid PWBs that have one or more flexible circuits laminated to them during the manufacturing process. Three-dimensional circuit assemblies can be created with rigid-flex combinations (EPA, 1995e).

1.2.2 Industry Profile

The total world market for PWBs is about $21 billion, with U.S. production accounting for about one quarter (more than $5 billion). The U.S.-dominated world market for PWBs eroded from 1980 to 1990, but has come back slightly in recent years. The PWB industry is characterized by highly competitive global sourcing with low profit margins (EPA, 1995e).

The U.S. has approximately 700 to 750 independent PWB manufacturing plants and about 70 captive facilities (e.g., original equipment manufacturers [OEMs] that make PWBs for use internally in their own electronic products) (EPA, 1995e). California, Minnesota, Texas, Illinois, Massachusetts, and Arizona have the highest number of PWB manufacturing plants, but there are PWB manufacturing facilities in virtually all 50 states and territories. More than 75 percent of U.S.-made PWBs are produced by independent shops (EPA, 1995e).

Around 90 percent of independent PWB manufacturers are small- to medium-sized businesses with annual sales under $10 million, but these shops only account for 20 to 25 percent of total U.S. sales (EPA, 1995e). Conversely, about seven percent of PWB manufacturers are larger independent shops with annual sales over $20 million, but these shops account for about 55 to 62 percent of total U.S. sales (EPA, 1995e).

Currently, rigid multi-layer boards dominate the domestic production value of PWBs, accounting for approximately 66 percent of the domestic market (EPA, 1995e). Double-sided boards account for about one quarter of the domestic market, with single-sided and flexible circuits making up the remainder. The market for multi-layer boards was about $3.4 billion in 1993, up from approximately $700 million in 1980 (EPA, 1995e).

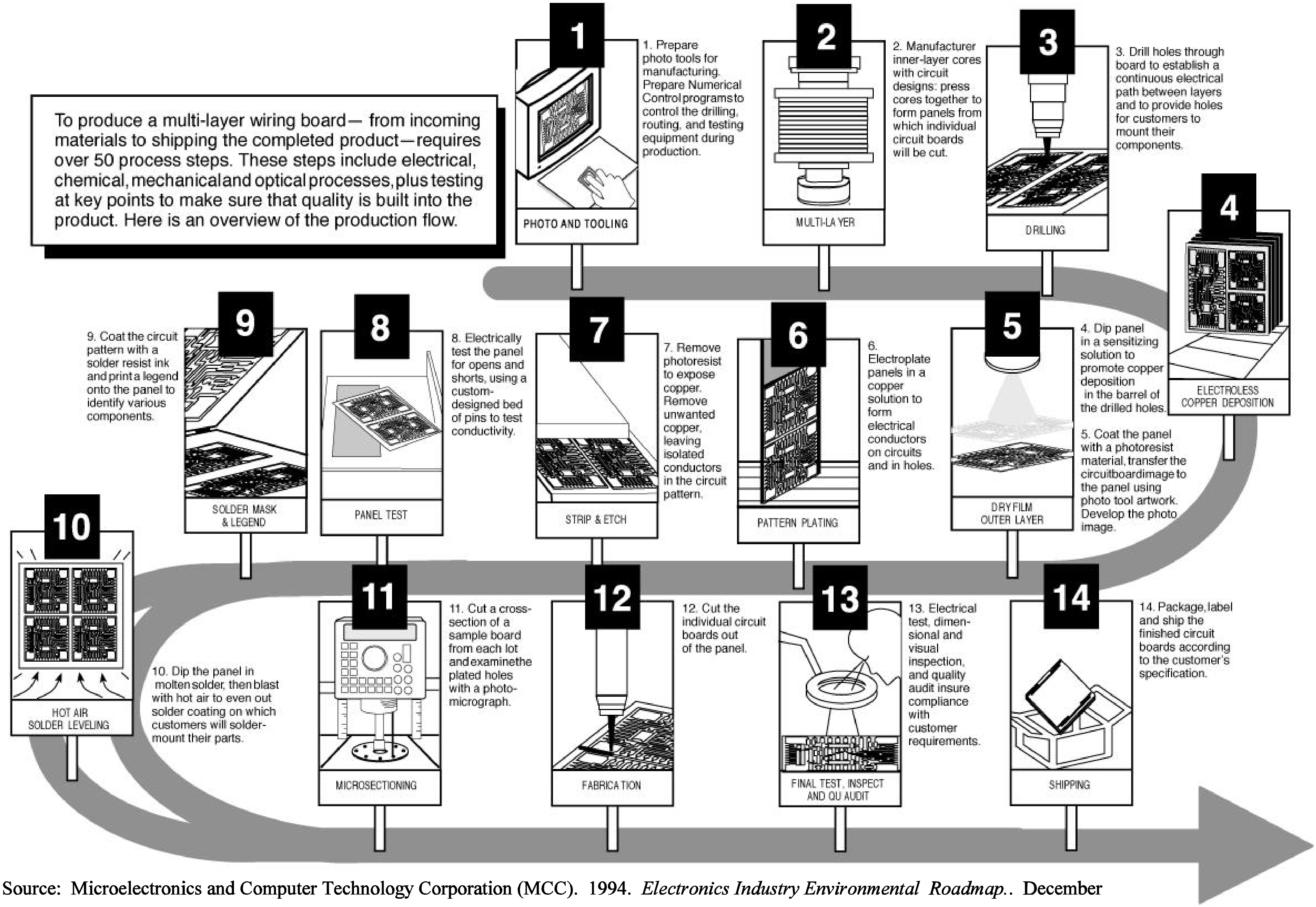
The PWB industry directly employs about 75,000 people, with about 68 percent of employment in production jobs. This is the highest ratio of production jobs for U.S. electronics manufacturing (EPA, 1995e). Additional jobs related to the industry are generated by PWB material and equipment suppliers and the OEMs that produce PWBs for internal use. Further information about the industry may be found in *Printed Wiring Board Industry and Use Cluster Profile* (EPA, 1995e).

1.2.3 Overview of Rigid Multi-Layer PWB Manufacturing

Multi-layer boards consist of alternating layers of conductor and insulating material bonded together. Holes are drilled through the boards to provide layer-to-layer connection on multi-layered circuits. Since most rigid PWB substrates consist of materials that will not conduct electricity (e.g., epoxy-resin and glass), a seed layer or coating of conductive material must be deposited into the hole barrels before electrolytic copper plating can occur. The MHC technologies evaluated in this report are processes to deposit this seed layer or coating of conductive material into drilled through-holes prior to electroplating. Traditionally, this has been done using an electroless copper technology to plate copper onto the hole barrels.

PWBs are most commonly manufactured by etching copper from a solid foil to form the desired interconnect pattern (subtractive processing). Another processing method, called additive processing, is used to selectively plate or metallize a board by building the circuits on catalyzed laminate with no metal foil on the surface. Additive processes to make multi-layer boards have only recently been under development in this country, and none are in widespread use (EPA, 1995e). Figure 1.1 illustrates the basic steps to fabricate rigid, multi-layer PWBs by subtractive processing.

Figure 1.1 Rigid, Multi-Layter PWB Manufacturing Process Flow Diagram



Source: Microelectronics and Computer Technology Corporation (MCC). 1994. *Electronics Industry Environmental Roadmap.*. December

1.3 CTSA METHODOLOGY

The CTSA *methodology* is a means of systematically evaluating and comparing human health and environmental risk, competitiveness (i.e., performance, cost, etc.), and resource requirements of traditional and alternative chemicals, manufacturing methods, and technologies in a particular use cluster. A use cluster is a set of chemical products, technologies, or processes that can substitute for one another to perform a particular function. A CTSA *document* is the repository for the technical information developed by a DfE project on a use cluster. Thus, MHC technologies comprise the use cluster that is the focus of this CTSA.

The overall CTSA methodology used in this assessment was developed by the EPA DfE Program, the UT Center for Clean Products and Clean Technologies, and other partners in voluntary, industry-specific pilot projects. The publication, *Cleaner Technologies Substitutes Assessment: A Methodology & Resource Guide* (Kincaid, et al., 1996) presents the CTSA methodology in detail. This section summarizes how the various technologies were selected for evaluation in the CTSA, identifies issues evaluated and data sources, and describes the project limitations. Chapters 2 through 6, and appendices, describe in detail the methods used to evaluate the technologies.

1.3.1 Identification of Alternatives and Selection of Project Baseline

Once the use cluster for the CTSA was chosen, industry representatives identified technologies that may be used to accomplish the MHC function. Initially, nine technology categories were identified, including seven wet chemistry processes, one screen printing process, and one mechanical process. These include:

- Wet chemistry: electroless copper, carbon, conductive polymer, electroless nickel, graphite, non-formaldehyde electroless copper, and palladium.
- Screen printing: conductive ink.
- Mechanical: lomerson.

Suppliers were contacted by EPA and asked to submit their product lines in these technology categories for evaluation in the CTSA. Criteria for including a technology in the CTSA were the following:

- It is an existing or emerging technology.
- There are equipment and facilities available to demonstrate its performance.

In addition, suppliers agreed to provide information about their technologies, including chemical product formulation data, process schematics, process characteristics and constraints (e.g., cycle time, limitations for the acid copper plating process, substrate and drilling compatibilities, aspect ratio capacity, range of hole sizes), bath replacement criteria, and cost information.

Product lines and publicly-available chemistry (e.g., product formulation) data were submitted for all of the technologies except electroless nickel and the lomerson process. Industry participants indicated the lomerson process is an experimental technology that has not been successfully implemented. Thus, seven categories of technologies were carried forward for further evaluation in the CTSA. After review of publicly-available chemistry data submitted by the suppliers, the palladium technology category was further divided into two technology categories—organic-palladium and tin-palladium—bringing the total number of technology categories slated for evaluation to eight. For the purposes of a Performance Demonstration conducted as part of this CTSA, however, the organic-palladium and tin-palladium technologies were grouped together into a single palladium technology category.

Further review of the technologies indicated that the conductive ink technology is not applicable to multi-layer boards and sufficient data were not available to characterize the risk, cost, energy, and natural resources consumption of all of the relevant process steps (i.e., preparation of screen for printing, the screen printing process itself, and screen reclamation). Thus, only a process description, chemical hazard data (i.e., safety hazards, human health hazards, and aquatic toxicity), and regulatory information are presented for the conductive ink technology.

The electroless copper technology was selected as the project baseline for the following reasons:

- It is generally regarded to be the industry standard and holds the vast majority of the market for MHC technologies.
- Possible risk concerns associated with formaldehyde exposure, the large amount of water consumed and wastewater generated by electroless copper processes, and the presence of chelators that complicate wastewater treatment have prompted many PWB manufacturers to independently seek alternatives to electroless copper.

As with other MHC technologies, electroless copper processes can be operated using vertical, immersion-type, non-conveyorized equipment or horizontal, conveyorized equipment. Conveyorized MHC equipment is a relatively new innovation in the industry and is usually more efficient than non-conveyorized equipment. However, most facilities in the U.S. still use a non-conveyorized electroless copper process to perform the MHC function. Therefore, the baseline technology was further defined to only include non-conveyorized electroless copper processes. Conveyorized electroless copper processes, and both non-conveyorized and conveyorized equipment configurations of the other technology categories are all considered to be alternatives to non-conveyorized electroless copper.

1.3.2 Boundaries of the Evaluation

For the purposes of the environmental evaluation (e.g., health and environmental hazards, exposure, risk, and resource consumption), the boundaries of this evaluation can be defined in terms of the overall life cycle of the MHC products and in terms of the PWB manufacturing process. The life cycle of a product or process encompasses extraction and processing of raw materials, manufacturing, transportation and distribution, use/re-use/maintenance, recycling, and final disposal. As discussed in Section 1.2.3, rigid, multi-layer PWB manufacturing encompasses a number of process steps, of which the MHC process is one.

The life-cycle stages evaluated in this study are primarily the use of MHC chemicals at PWB facilities and the release or disposal of MHC chemicals from PWB facilities. However, in addition to evaluating the energy consumed during MHC line operation, the analysis of energy impacts (Section 5.2) also discusses the pollutants generated from producing the energy to operate the MHC line as well as energy consumed in other life-cycle stages, such as the manufacture of chemical ingredients. In addition, while information is presented on the types and quantities of wastewater and solid waste generated by MHC process lines, there was insufficient information to characterize the risk from these environmental releases. This is discussed in more detail in Section 3.1, Source Release Assessment.

In terms of the PWB manufacturing process, this analysis focused entirely on the MHC process, defined as beginning with a panel that has been desmeared[2] and freed of all residual desmear chemistry and ending when a layer of conducting material has been deposited that is stable enough to proceed to either panel or pattern plating. The MHC process was defined slightly differently however, for the Performance Demonstration: beginning with the desmear step, proceeding through the MHC process, and ending with 0.1 mil of copper flash plating. The slightly different definition was needed to address compatibility issues associated with the desmear step and to protect the test boards during shipment to a single facility for electroplating (see Section 4.1, Performance Demonstration Results).

The narrow focus on MHC technologies yields some benefits to the evaluation, but it also has some drawbacks. Benefits include the ability to collect extremely detailed information on the relative risk, performance, cost, and resources requirements of the baseline technology and alternatives. This information provides a more complete assessment of the technologies than has previously been available and would not be possible if every step in the PWB manufacturing process was evaluated. Drawbacks include the inability to identify all of the plant-wide benefits, costs, or pollution prevention opportunities that could occur when implementing an alternative to the baseline electroless copper technology. However, given the variability in workplace practices and operating procedures at PWB facilities, these other benefits and opportunities are expected to vary substantially among facilities and would be difficult to assess in a comparative evaluation such as a CTSA. Individual PWB manufacturers are urged to assess their overall operations for pollution prevention opportunities when implementing an alternative technology.

1.3.3 Issues Evaluated

The CTSA evaluated a number of issues related to the risk, competitiveness, and resource requirements (conservation) of MHC technologies. These include the following:

- Risk: occupational health risks, public health risks, ecological hazards, and process safety concerns.
- Competitiveness: technology performance, cost, regulatory status, and international market status.
- Conservation: energy and natural resource use.

[2] Desmearing is the process step to remove a small amount of epoxy-resin from the hole barrels, including any that may have been smeared across the copper interface during drilling.

Occupational and public health risk information is for chronic exposure to long-term, day-to-day releases from a PWB facility rather than short-term, acute exposures to high levels of hazardous chemicals as could occur with a fire, spill, or other periodic release. Risk information is based on exposures estimated for a model facility, rather than exposures estimated for a specific facility. Ecological hazards, but not risks, are evaluated for aquatic organisms that could be exposed to MHC chemicals in wastewater discharges. Process safety concerns are summarized from material safety data sheets (MSDSs) for the technologies and process operating conditions.

Technology performance is based on a snapshot of the performance of the MHC technologies at volunteer test sites in the U.S. and abroad. Panels were electrically prescreened, followed by electrical stress testing and mechanical testing, in order to distinguish variability in the performance of the MHC interconnect. Comparative costs of the MHC technologies were estimated with a hybrid cost model that combines traditional costs with simulation modeling and activity-based costs. Costs are presented in terms of dollars per surface square feet (ssf) of PWB produced.

Federal environmental regulatory information is presented for the chemicals in the MHC technologies. This information is intended to provide an indication of the regulatory requirements associated with a technology, but not to serve as regulatory guidance. Information on the international market status of technologies is presented as an indicator of the effects of a technology choice on global competitiveness.

Quantitative resource consumption data are presented for the comparative rates of energy and water use of the MHC technologies. The large amounts of water consumed and wastewater generated by the traditional electroless copper process have been of particular concern to PWB manufacturers, as well as to the communities in which they are located.

1.3.4 Primary Data Sources

Much of the process-specific information presented in this CTSA was provided by chemical suppliers to the PWB industry, PWB manufacturers who responded to project information requests, and PWB manufacturers who volunteered their facilities for a performance demonstration of the baseline and alternative technologies. The types of information provided by chemical suppliers and PWB manufacturers are summarized below.

Chemical Suppliers

The project was open to any chemical supplier who wanted to participate, provided their technologies met the criteria described in Section 1.3.1. Table 1.1 lists the suppliers who participated in the CTSA and the categories of MHC technologies they submitted for evaluation. It should be noted that this is not a comprehensive list of MHC technology suppliers. EPA made every effort to publicize the project through trade associations, PWB manufacturers, industry conferences and other means, but some suppliers did not learn of the project until it was too late to submit technologies for evaluation.

Table 1.1 MHC Technologies Submitted by Chemical Suppliers

Chemical Supplier	MHC Technology							
	Electroless Copper	Carbon	Conductive Ink	Conductive Polymer	Graphite	Non-Formaldehyde Electroless Copper	Organic-Palladium	Tin-Palladium
Atotech U.S.A., Inc.	✓			✓			✓	
Electrochemicals, Inc.	✓				✓			
Enthone-OMI, Inc.	✓							✓
W.R. Grace and Co.			✓					
LeaRonal, Inc.								✓
MacDermid, Inc.	✓	✓				✓		
Shipley Company	✓				✓			✓
Solution Technology Systems								✓

Each of the chemical suppliers provided the following: MSDSs for the chemical products in their MHC technology lines; Product Data Sheets, which are technical specifications prepared by suppliers for PWB manufacturers that describe how to mix and maintain the chemicals baths; and, in some cases, copies of patents.[3] Suppliers were also asked to complete a Supplier Data Sheet, designed for the project, which included information on chemical cost, equipment cost, water consumption rates, product constraints, and the locations of test sites for the Performance Demonstration. Appendix A contains a copy of the Supplier Data Sheet.

PWB Manufacturers

PWB manufacturers were asked to participate in a study of workplace practices. The IPC Workplace Practices Questionnaire requested detailed information on facility size, process characteristics, chemical consumption, worker activities related to chemical exposure, water consumption, and wastewater discharges. The questionnaire was distributed to PWB manufacturers by IPC. PWB manufacturers returned the completed questionnaires to IPC, which removed all facility identification and assigned a code to the questionnaires prior to forwarding them to the UT Center for Clean Products. In this manner, PWB manufacturers were guaranteed confidentially of data. However, when Center staff had follow-up questions on a questionnaire response, many facilities allowed the Center to contact them directly, rather than go through IPC to discuss the data.

For the Performance Demonstration project the IPC Workplace Practices Questionnaire was modified and divided into two parts: a Facility Background Information Sheet and an Observer Data Sheet. The Facility Background Information Sheet was sent to PWB facilities participating in the Performance Demonstration prior to their MHC technology test date. It requested detailed information on facility and process characteristics, chemical consumption, worker activities related to chemical exposure, water consumption, and wastewater discharges. The Observer Data Sheet was used by an on-site observer to collect data during the Performance

[3] In addition, Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. This is discussed further in Section 1.3.5.

Demonstration. In addition to ensuring that the performance test was performed according to the agreed upon test protocol, the on-site observer collected measured data, such as bath temperature and process line dimensions, and checked survey data for accuracy. Appendix A contains copies of the IPC Workplace Practices Questionnaire, the Facility Background Information Sheet, and the Observer Data Sheet forms.

Table 1.2 lists the number of PWB manufacturing facilities that completed the IPC Workplace Practices Questionnaire (original forms modified for the Performance Demonstration) by type of MHC process, excluding responses with poor or incomplete data. Of the 59 responses to the questionnaire, 25 were Performance Demonstration test sites.

Table 1.2 Responses to the Workplace Practices Questionnaire

MHC Technology	No. of Responses	MHC Technology	No. of Responses
Electroless Copper	36	Non-Formaldehyde Electroless Copper	1
Carbon	2	Organic-Palladium	2
Conductive Polymer	1	Tin-Palladium	13
Graphite	4		

Information from the pollution prevention and control technologies survey conducted by the DfE PWB Project was also used in the CTSA. These data are described in detail in the EPA publication, *Printed Wiring Board Pollution Prevention and Control: Analysis of Survey Results* (EPA, 1995a).

1.3.5 Project Limitations

There are a number of limitations to the project, both because of the project's limited resources, the predefined scope of the project, and data limitations inherent to risk characterization techniques. Some of the limitations related to the risk, competitiveness, and conservation components of the CTSA are summarized below. More detailed information on limitations and uncertainties for a particular portion of the assessment is given in the applicable sections of this document. A limitation common to all components of the assessment is that the MHC chemical products assessed in this report were voluntarily submitted by participating suppliers and may not represent the entire MHC technology market. For example, the electroless nickel and lomerson technologies were not evaluated in the CTSA.

Risk

The risk characterization is a screening level assessment of multiple chemicals used in MHC technologies. The focus of the risk characterization is on chronic (long-term) exposure to chemicals that may cause cancer or other toxic effects, rather than on acute toxicity from brief exposures to chemicals. The exposure assessment and risk characterization use a "model facility" approach, with the goal of comparing the exposures and health risks of the MHC process alternatives to the baseline electroless copper technology. Characteristics of the model facility were aggregated from questionnaire data, site visits, and other sources. This approach does not result in an absolute estimate or measurement of risk.

In addition, the exposure and risk estimates reflect only a portion of the potential exposures within a PWB manufacturing facility. Many of the chemicals found in MHC technologies may also be present in other process steps of PWB manufacturing and other risk concerns for human health and the environment may occur from other process steps. Incremental reduction of exposures to chemicals of concern from an MHC process, however, will reduce cumulative exposures from all sources in a PWB facility, provided that increased production does not increase plant-wide pollution.

Finally, information presented in this CTSA is based on publicly-available chemistry data submitted by each of the participating suppliers, as well as proprietary data submitted by Electrochemicals, LeaRonal, and Solution Technology Systems. W.R. Grace was preparing to submit proprietary data for the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Atotech, Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information. The absence of information on proprietary chemical ingredients is a significant source of uncertainty in the risk characterization. Risk information for proprietary ingredients, as available, is included in this CTSA, but chemical identities and chemical properties are not listed.

Competitiveness

The Performance Demonstration was designed to provide a snapshot of the performance of different MHC technologies. The test methods used to evaluate performance were intended to indicate characteristics of a technology's performance, not to define parameters of performance or to substitute for thorough on-site testing. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities in the U.S. (although there is no specific reason to believe they are not representative).

The cost analysis presents comparative costs of using an MHC technology in a model facility to produce 350,000 ssf of PWBs. As with the risk characterization, this approach results in a comparative evaluation of cost, not an absolute evaluation or determination. The cost analysis focuses on private costs that would be incurred by facilities implementing a technology. It does not evaluate community benefits or costs, such as the effects on jobs from implementing a more efficient MHC technology. However, the Social Benefits/Costs Assessment (see Section 7.2) qualitatively evaluates some of these external (i.e., external to the decision-maker at a PWB facility) benefits and costs.

The regulatory information contained in the CTSA may be useful in evaluating the benefits of moving away from processes containing chemicals that trigger compliance issues. However, this document is not intended to provide compliance assistance. If the reader has questions regarding compliance concerns, they should contact their federal, state, or local authorities.

Conservation

The analysis of energy and water consumption is also a comparative analysis, rather than an absolute evaluation or measurement. Similar to the cost analysis, consumption rates were estimated based on using an MHC technology in a model facility to produce 350,000 ssf of PWB.

1.4 ORGANIZATION OF THIS REPORT

This CTSA is organized into two volumes: Volume I summarizes the methods and results of the CTSA; Volume II consists of appendices, including detailed chemical properties and methodology information, and comprehensive results of the risk characterization.

Volume I is organized as follows:

- Chapter 2 gives a detailed profile of the MHC use cluster, including process descriptions of the MHC technologies evaluated in the CTSA and the estimated concentrations of chemicals present in MHC chemical baths.
- Chapter 3 presents risk information, beginning with an assessment of the sources, nature, and quantity of selected environmental releases from MHC processes (Section 3.1); followed by an assessment of exposure to MHC chemicals (Section 3.2) and the potential human health and ecological hazards of MHC chemicals (Section 3.3). Section 3.4 presents quantitative risk characterization results, while Section 3.5 discusses process safety concerns.
- Chapter 4 presents competitiveness information, including Performance Demonstration results (Section 4.1), cost analysis results (Section 4.2), regulatory information (Section 4.3), and international market information (Section 4.4).
- Chapter 5 presents conservation information, including an analysis of water and other resource consumption rates (Section 5.1) and energy impacts (Section 5.2).
- Chapter 6 describes additional pollution prevention and control technology opportunities (Sections 6.1 and 6.2, respectively).
- Chapter 7 organizes data collected or developed throughout the CTSA in a manner that facilitates decision-making. Section 7.1 presents a summary of risk, competitiveness and conservation data. Section 7.2 assesses the social benefits and costs of implementing an alternative as compared to the baseline. Section 7.3 provides summary profiles for the baseline and each of the MHC alternatives.

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